Environmental Risks of Cadmium
The European Perspective

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European Regulations on environmental Cd

- Cd limits in food, sludge and soils receiving sludge

wheat grain limit is 0.2 mg/kg!

European initiatives to assess risk of Cd in the environment

- The EU risk assessment of Cd/CdO (1997-2005)
- The EU risk assessment of Cd in fertilisers (finished 2001)
- The EU sludge directives (not finished)
- The assessment of 'critical loads' (atmospheric deposition, not finished)

National Regulations

- Cd limits in soil, water, sediment; voluntary limits for Cd in fertilisers in 6 countries, mandatory limits in 3 countries

Conclusions of both risk assessments:

- EU wide risk assessment identified risk and recommended that risks have to be reduced

- No practical implementations (e.g. EU wide limits of Cd in fertilisers) are yet in place

The EU risk assessment on Cd/CdO

Follows Council Regulation (EEC) 793/93

- Risk assessment required for existing chemicals in EU
- A ‘generic approach’ for the entire EU
- Risk assessment of ‘current emissions’ to protect man and the environment
- The assessment was concluded end 2005
- Current activities are devoted to ‘the risk reduction phase’

Final drafts of the Risk Assessment cadmium oxide and of the Risk Assessment cadmium metal available at the following address : http://ecb.jrc.it/existing-chemicals/ under the references R3020307 env hh and R3030307 env hh.

The EU risk assessment on Cd/CdO

Conclusions for ‘environmental Cd’

General population

conclusion (iii) There is a need for limiting the risks

Environment, soil at the ‘regional scale’

conclusion (iii) There is a need for limiting the risks

Why risk of Cd for man exposed via the environment?

Upper percentiles of measured urinary Cd concentrations (Cd-U) in general population exceed safe values (NOAEL); modelled values predict same conclusions for some segments of the population

Why risk of Cd for the environment?

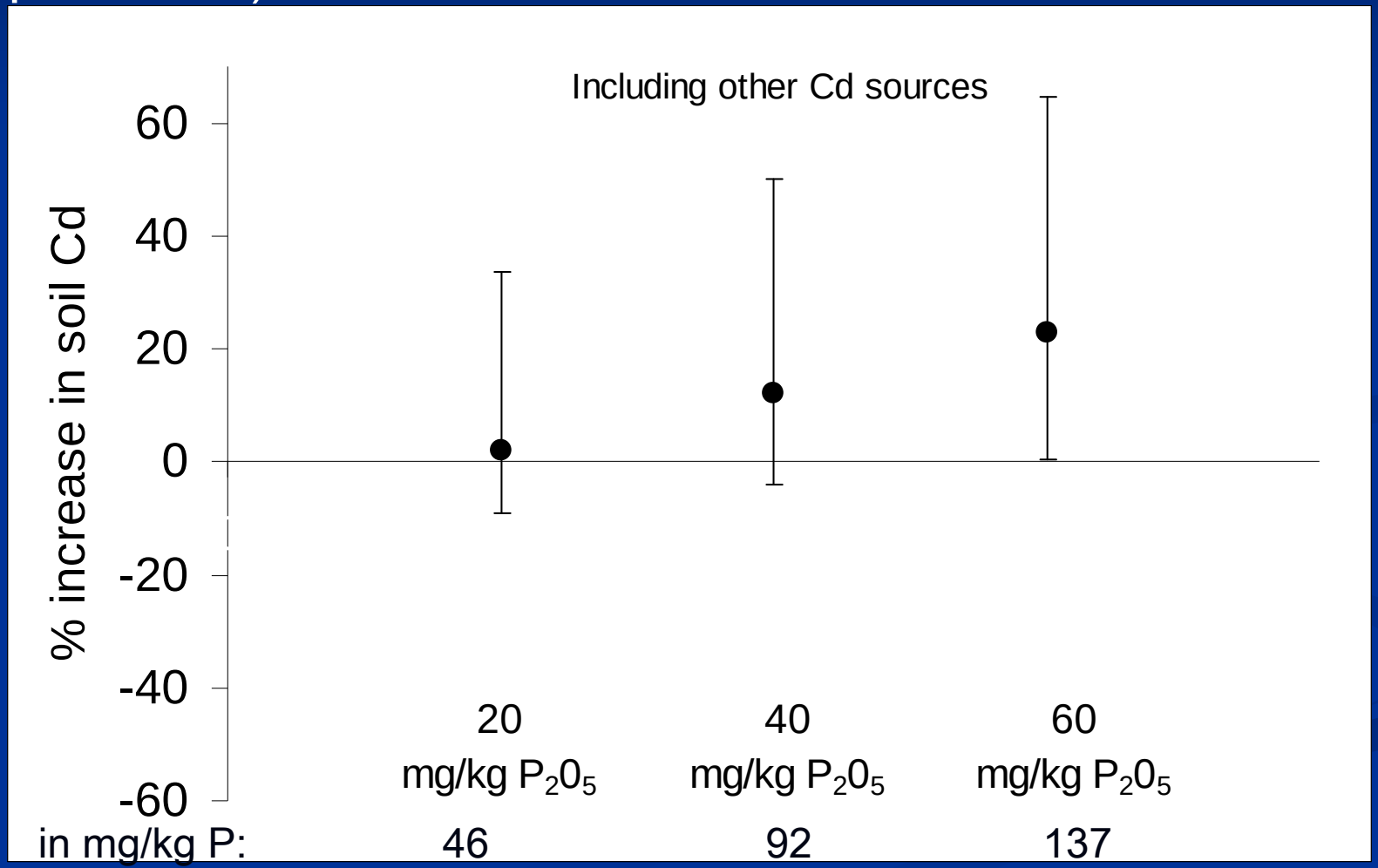
Upper percentiles of soil Cd in EU (assessed away from point sources) exceed the PNEC (Predited No Effect Concentration) to protect soil organisms.

The EU risk assessment on Cd in fertilisers

- Nine countries performed a national risk assessment
- Conclusion: ‘The problem is neither urgent nor acute, however accumulation should be prevented’
- The summary of the assessment resulted in 2002 in a recommendation for stepwise introducing an EU wide limit of Cd in fertilisers
- An internet consultation was made in 2003
- An socio-economic impact study of the limits was made in 2003
- The discussion was postponed until the end of the EU risk assessment of Cd/CdO (end 2005)
- EU wide limits are not yet in place

http://europa.eu.int/comm/enterprise/chemicals/fertilizers/riskassest/reports.htm

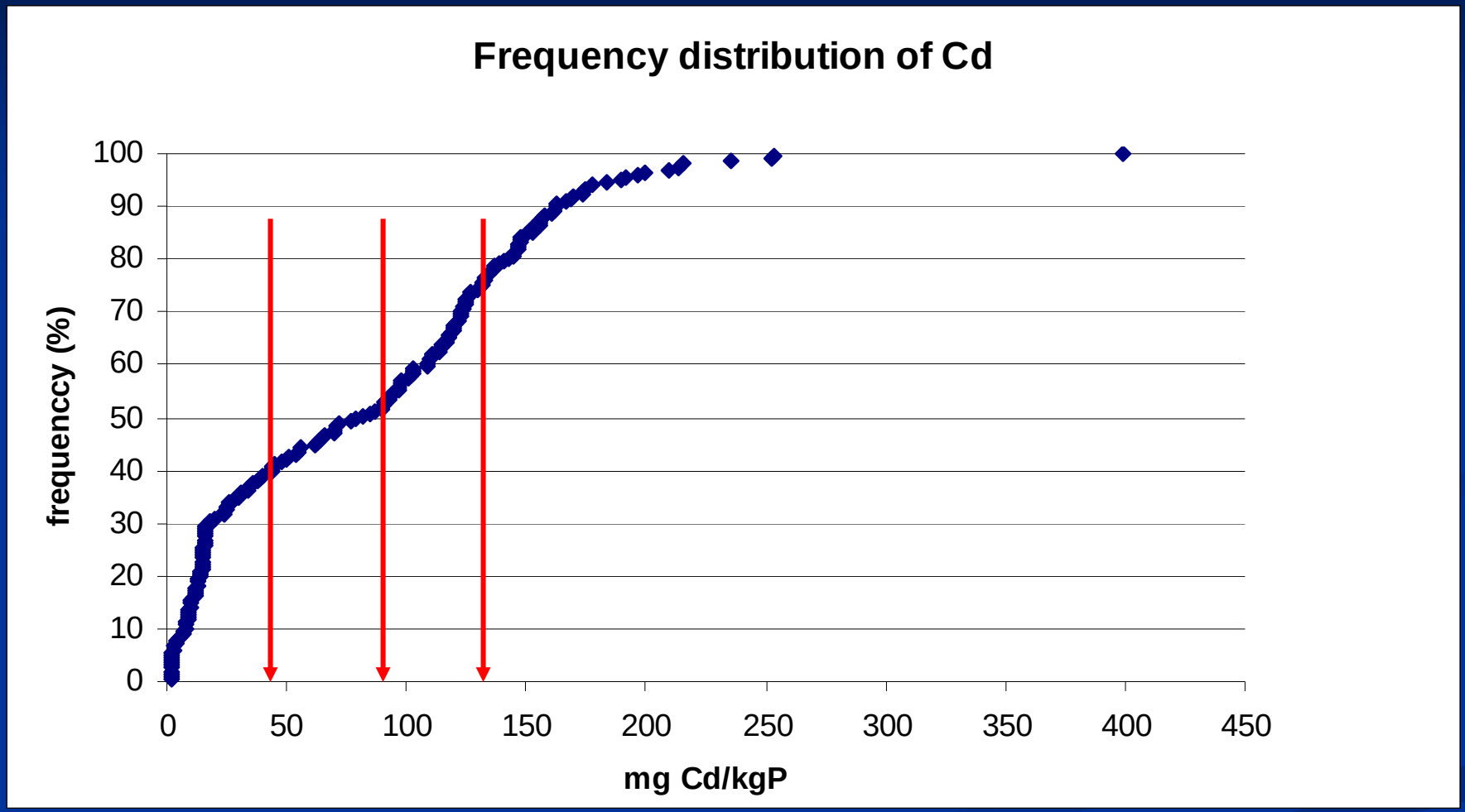
Proposed limits are based on a mass balance calculation: predicted change in soil Cd in EU after 100 years at 3 concentrations of Cd in fertiliser. Means (10-90th percentile) of different scenarios



Proposed limits

- 5 years after the entry into force of this Regulation the limit will be 60 mg of Cd/kg P_2O_5
- 10 years after the entry into force of this Regulation the limit will be 40 mg of Cd/kg P_2O_5
- 15 years after the entry into force of this Regulation the limit will be 20 mg of Cd/kg P_2O_5

Current concentrations in fertilisers (EU wide survey)



(Nziguheba&Smolders, 2005, unpublished)

Internet consultation organised by the EU, DG Enterprise about the proposal. Replies are broadly classified as for, against and neutral, with respect to limits stricter than 60 mg Cd/ kg P_2O_5

	Total answers	For	Against	Neutral
Industry and Trade	39	2 Russia, Finland	37	0
Public authorities	11	4 Denmark Finland Sweden Ministry of environment of Lower Saxony	4 Austria Germany Spain U.S.A. (T.F.I.)	3 Switzerland Romania (Agri. R and D) State institute for agriculture of Saxony
miscellaneous sources	8	1 Denmark	6	1
Distributors and agricultural co-operative	6	0	6	0
Trade Unions	1	0	1	0
TOTAL	**65**	7	**54**	**4**

Note: the European Fertiliser Manufacterer Association proposes a limit of 60 mg Cd/kg P_20_5

The EU risk assessment on Cd/CdO

- Cd risk assessment started in 1997, approved by 'Technical Meeting'[1] in December 2005
- Draft report does reflect the view of the majority of the 'Technical Meeting'[1] and not that of the 'rapporteur' only

[1]Competent Group of Member State experts for endorsement, Observers from Industry, Consumer Organisations, Trade Unions, Environmental Organisations and certain International Organisations

Risk Assessment of Cd. Part I: environment

Emission data→ predicted environmental concentrations (PEC)

Effects data→predicted no effect concentrations (PNEC)

Risk Assessment of Cd. I. Environment, exposure

1996 statistics

5800 ton Cd produced/imported annually in EU
75% used in NiCd batteries, 15 % in pigments, 10% in plating, alloys and stabilisers

Emissions (ton Cd/y)

	Cd industry 1982	Cd industry 1996	diffuse 1990-2001
Air	28	4.7	±140
Water	157	1.6	±40
Soil			±240

Risk Assessment of Cd. I. Environment, exposure

Exposure assessment

Local: water, sediment, soil

Regional and continental: water, sediment, soil

Risk Assessment of Cd. I. Environment, exposure

Mass balances in soil (g Cd/ha/y) in UK and DK

	historical	current
Fertiliser	1.5-5	0.8-2.1
Atmospheric deposition	>3-8	0.4-1.8
Crop offtake	0.2-2	0.2-2
Leaching	1-5	?
Net input	+3 to +7	-2 to+1.2

Risk Assessment of Cd. I. Environment, exposure

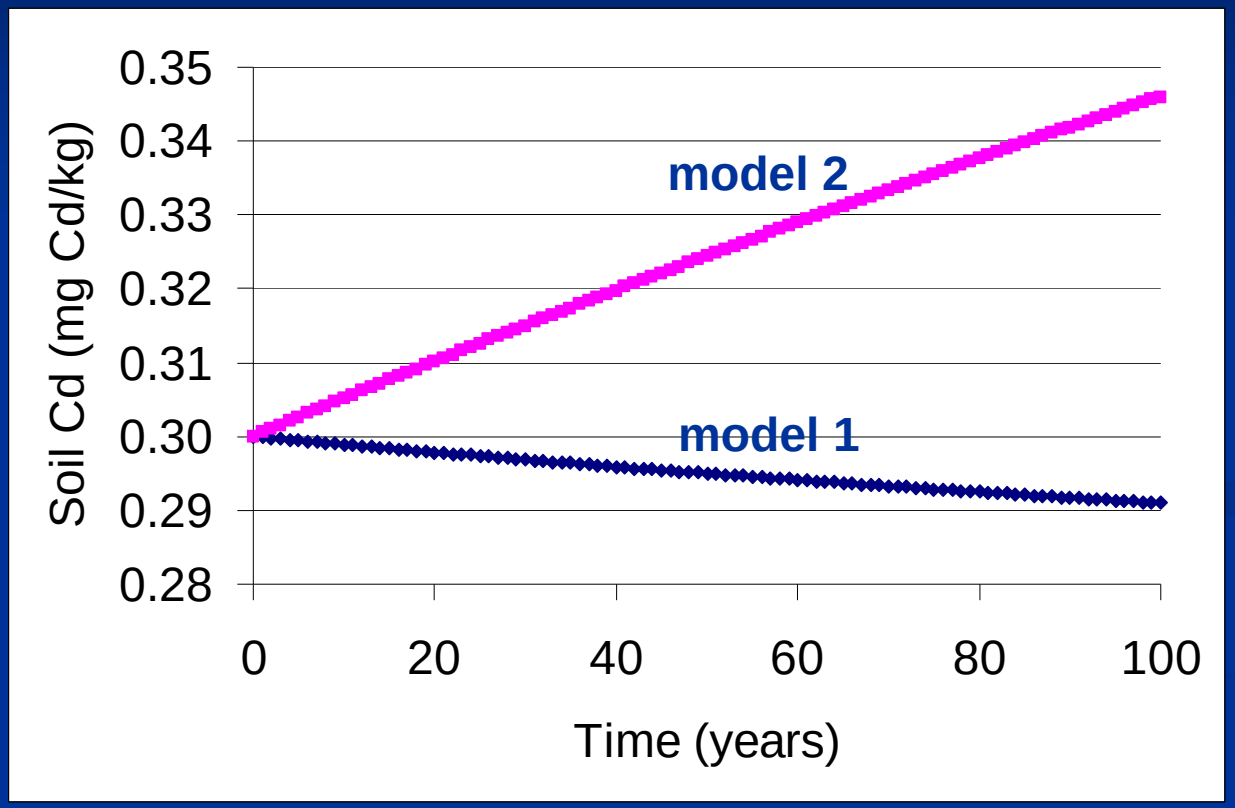
Largest uncertainties:

1. **What is the net atmospheric deposition? EU wide averaged deposition is about 1 g/ha/y and all atmospheric emissions divided by the surface predict 0.4 g/ha/y. Measured data may include resuspended particles**

2. **The leaching model needs more validation**

Risk Assessment of Cd. I. Environment, exposure

Losses of Cd by leaching: type of model determines the predicted Cd trend!



mass balance (g/ha/y)

fertiliser:	2.5
atmosphere:	1.2
crop offtake	0.3

leaching = pore water Cd and 200 mm net water loss

Pore water Cd: 2 models (1=Römkens and Salomons, 1998; 2= Smolders, unpublished)

Risk Assessment of Cd. I. Environment, exposure

predicted soil Cd in agricultural soils with current Cd input in EU

7 scenario's to represent major EU agricultural practices

input (g Cd/ha/y)		% change in soil Cd after 60 years
fertiliser	atmosphere	
1.1-4.5	0.6-3.0	-19% to +37% (mean + 6%)

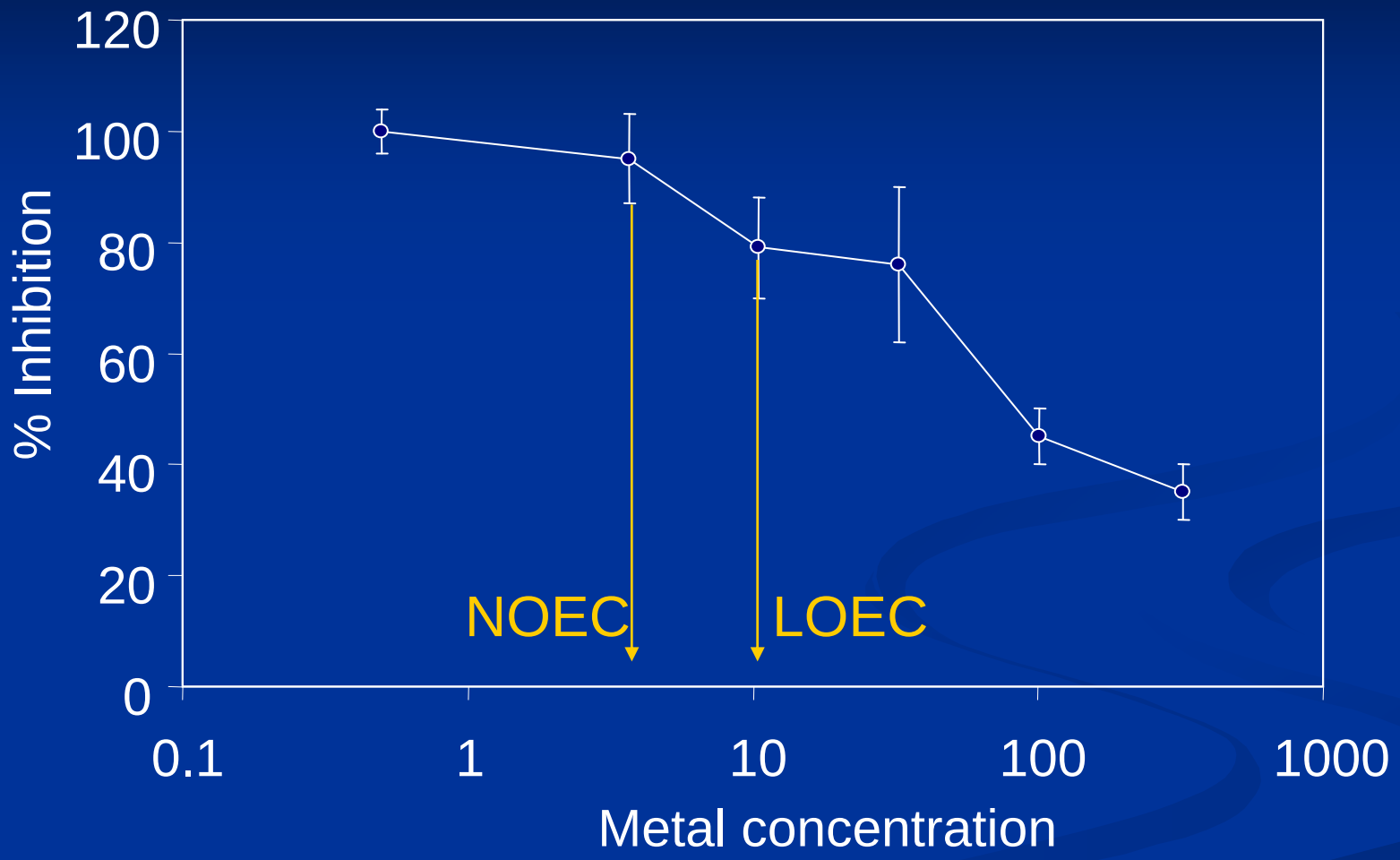
"It can be concluded that the current Cd input in European agricultural soils is reduced from historical input and that the European soil Cd concentration is predicted to change by between a 19% decrease to a 37% increase (mean: 6%) in 60 years...it appears that estimating Cd leaching losses is critical for drawing firm conclusions"

Risk Assessment of Cd. I. Environment, effects

Effects assessment for the environment

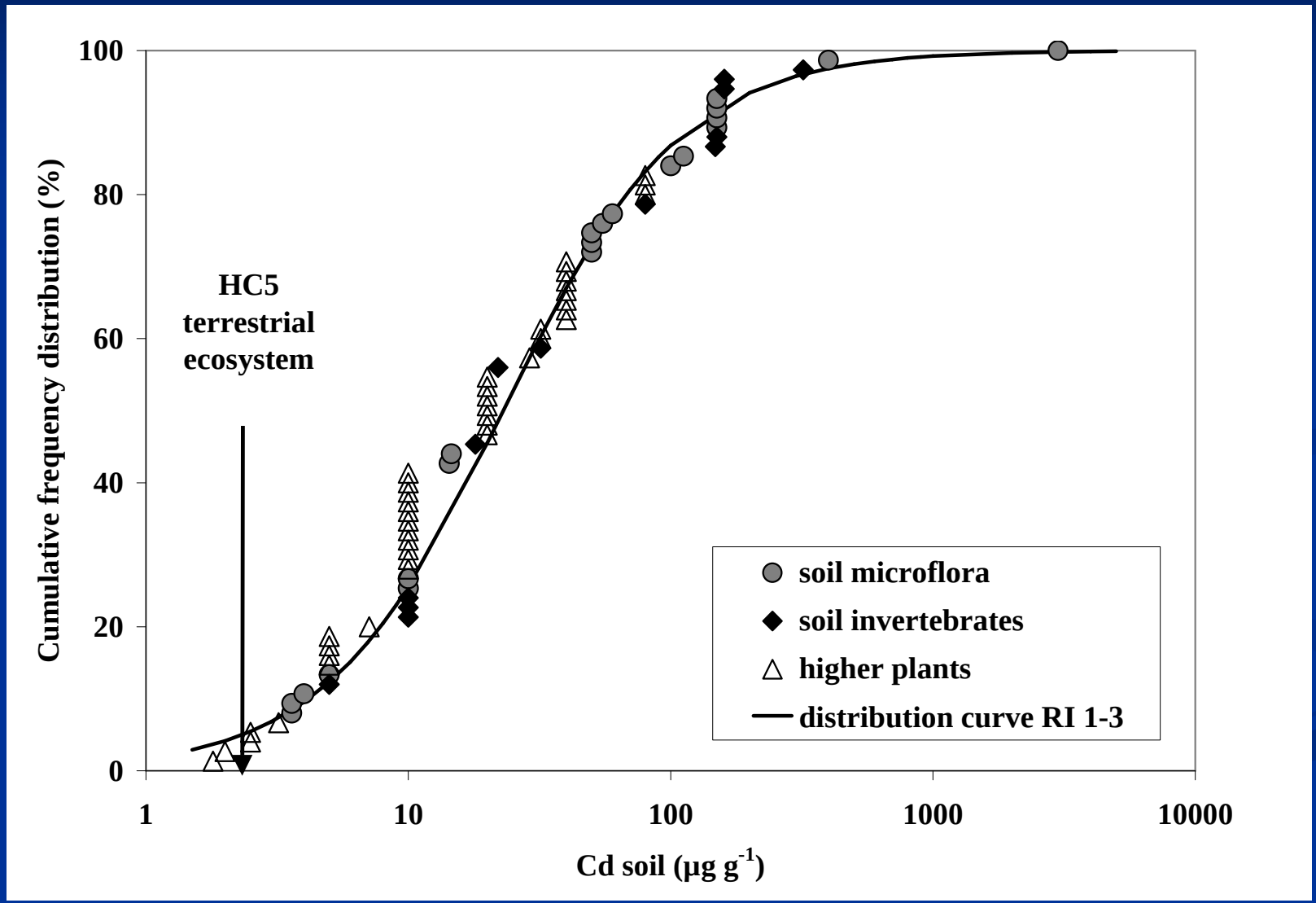
Water
Sediment
Soil (plants, invertebrates, microbial processes)
Assessment of secondary poisoning from water or soil (birds, mammals)

Risk Assessment of Cd. I. Environment, effects



Risk Assessment of Cd. I. Environment, effects

The cumulative frequency distribution of the NOEC values of Cd toxicity tests with soil microflora, invertebrates and higher plants



Risk Assessment of Cd. I. Environment, effects

1. **The 'Predicted No Effect Concentration' for soil biota and soil microbial processes**

   PNECsoil = 1.15-2.3 mg Cd/kg

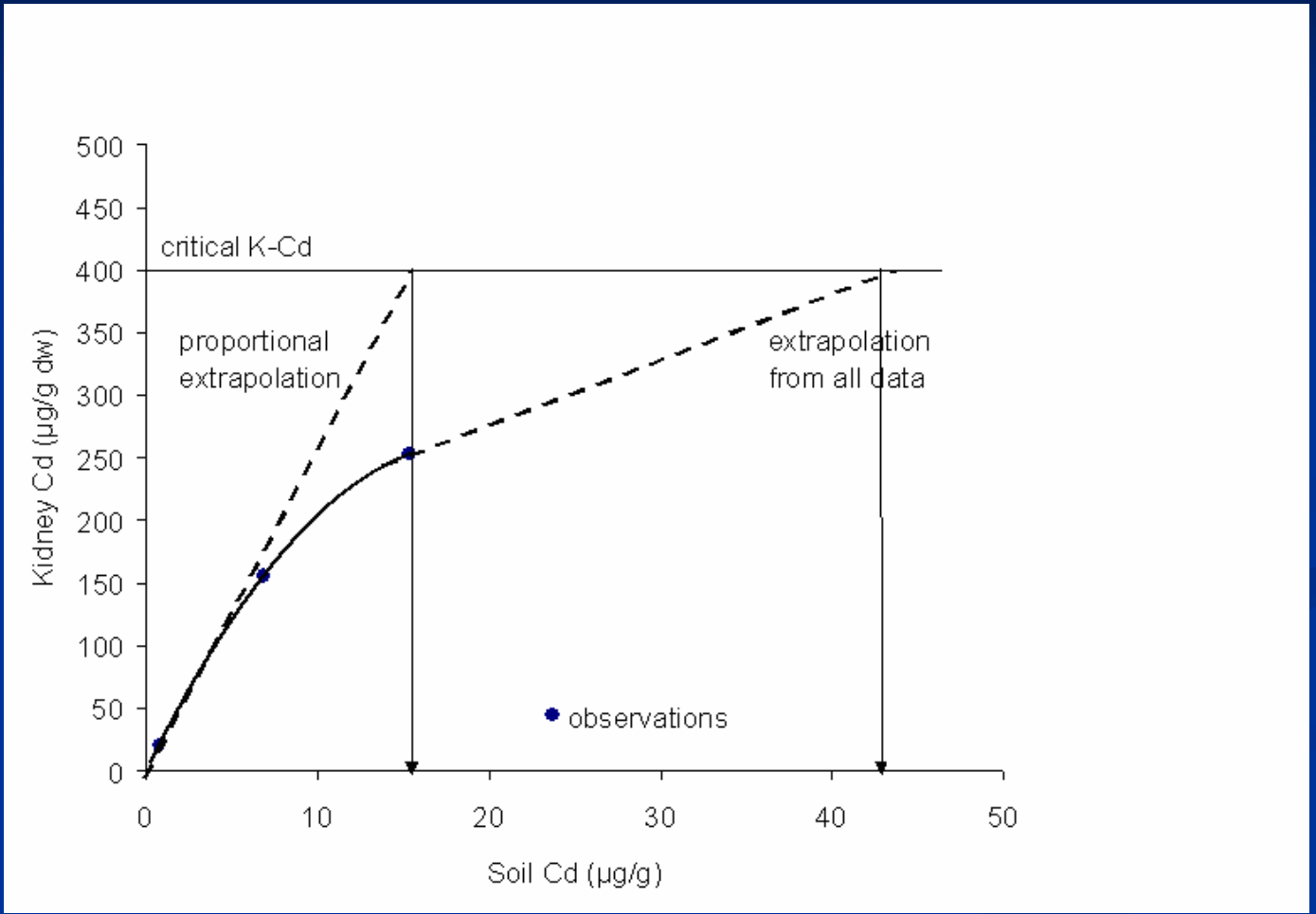
   Note: no model was available to correct the PNEC as a function of soil properties

Risk Assessment of Cd. I. Environment, effects

2. Secondary poisoning to wildlife

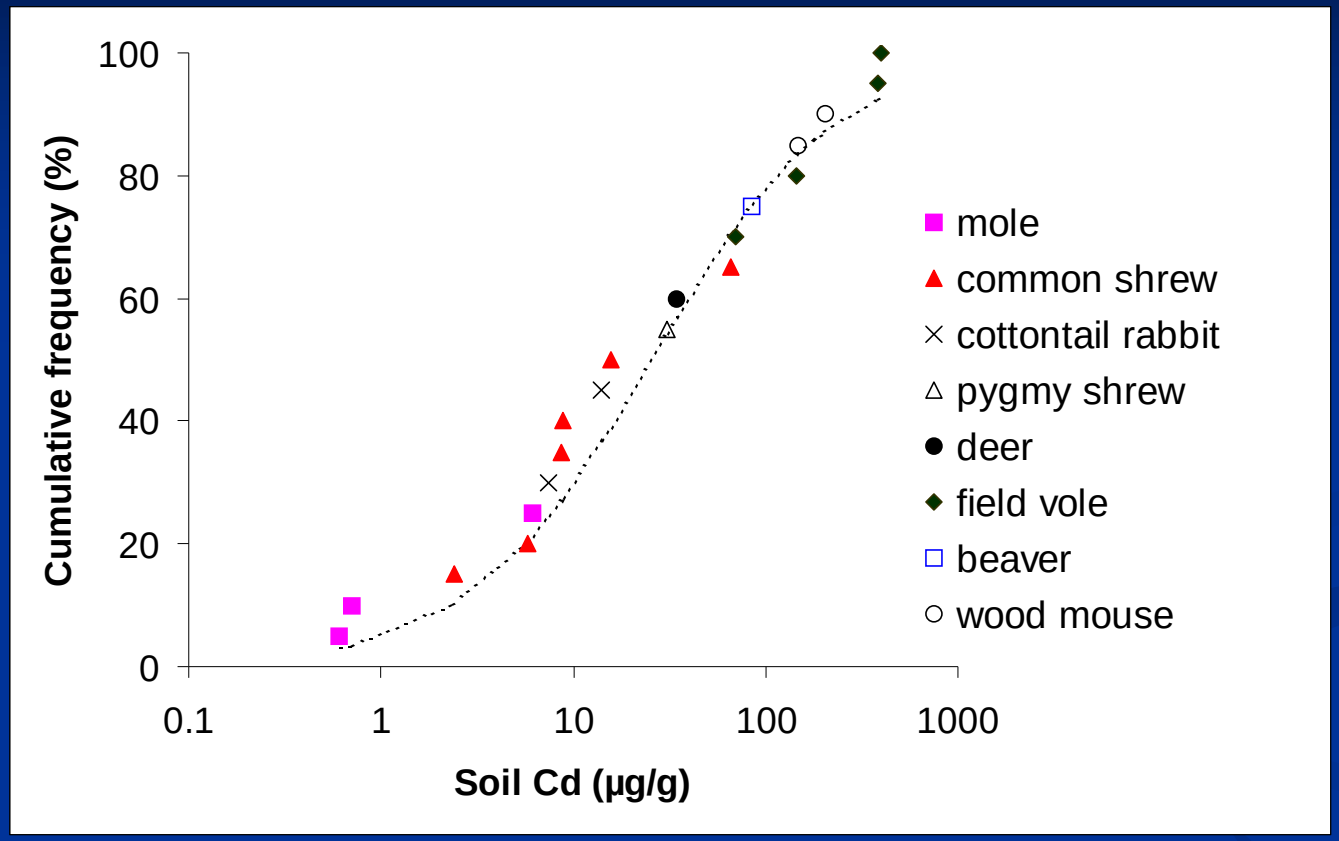
Body burden Cd is acceptable for most wildlife at the ‘critical soil Cd’. Assessment is based on soil and kidney Cd concentration data in wildlife

Risk Assessment of Cd. I. Environment, effects



Data from Cd in common shrew (*S. araneus*) in a transect study (Hunter et al., 1989).

Risk Assessment of Cd. I. Environment, effects



Cumulative frequency of the critical soil Cd concentration at which the critical kidney Cd concentration (400 µg/g dw) may be exceeded in the average population of different species

Risk Assessment of Cd. I. Environment, effects

2. The ‘Predicted No Effect Concentration’ for protecting wildlife from elevated Cd exposure

PNECsoil = 0.9 mg Cd/kg

Note: no model was available to correct the PNEC as a function of soil properties

Risk Assessment of Cd. I. Environment, risk characterisation

Final conclusion for soil, regional assessment:

“risk cannot be excluded in EU because 90th percentiles of measured Cd concentrations exceed the PNEC in some regions”

Risk Assessment of Cd. II. Human health

Exposure assessment:	consumer exposure
	occupational exposure
	indirect exposure via the environment
Effects assessment:	toxickinetics
	acute toxicity, irritation,...
	repeated dose toxicity
	carcinogicity
	genotoxicity
	toxicity for reproduction

Risk Assessment of Cd. II. Human health

Indirect exposure via the environment (general population)

"average dietary Cd intake values range from 7-32 µg day^{-1} with a tendency to find lowest values in Scandinavian countries and highest values in Mediterranean countries"

"limited data from UK, The Netherlands, Denmark and Sweden show that upper percentiles (95^{th} or higher) of dietary Cd intake range between 24 and 40 µg day^{-1}"

Risk Assessment of Cd. II. Human health

"smoking and dietary Cd intake are major sources of Cd for the general population"

scenario 1: adults with sufficient body iron stores		
source	Cd uptake (µg day^{-1})	assumptions
air	0.025 -0.075	air Cd 5-15 ng m^{-3}; daily inhalation 20 m^3; absorption rate = 0.25
soil and dust	0.02	dust or soil Cd 7 mg kg^{-1}; absorption rate = 0.03
smoking	0.5-2.0	smoking of 20 cigarettes; 1-2 µg Cd $cigarette^{-1}$; absorbed fraction 0.025-0.05
drinking water	<0.06	Cd water<1 µg L^{-1}; absorption rate = 0.03 2L day^{-1} consumption
dietary intake	0.21-0.96	dietary Cd 7-32 µg day^{-1}, absorption rate = 0.03
sum	**non smokers: 0.33-1.12** **smokers: 0.82-3.12**	

Risk Assessment of Cd. II. Human health

"The critical target organs for cadmium in the general population are the kidney and bone"

"On the basis of the available studies, it appears probable, however, that the earliest renal effects may occur in the general population at Cd-U>2 µg/g creatinine"

"It is proposed that a Margin of Safety of 3 would be sufficient to protect the population in order to mainly take into account the conversion of a LOAEL→NOAEL, i.e. the **NOAEL is 2/3= 0.66 µg Cd/g creatinine"**

Risk Assessment of Cd. II. Human health

Upper percentiles of measured Cd-U data in general population exceed NOAEL

Measured data (incl. smokers)	Cd-U (µg/g creatinine)
Fiolet et al. 1999 (RIVM)	GM : 0.44 Median : 0.34 P95 : 1.35
Umwelt Bundes Amt. 2000	Median 0.18 P10 : 0.06 P90 : 0.55 P95 : 0.74 P98 : 1.10
NHNES 1999 (CDC, US)	GM : 0.29 P10 : 0.11 P25 : 0.17 P50 : 0.27 P75 : 0.46 P90 : 0.74

Note: NOAEL is 2/3= 0.66 µg Cd/g creatinine

Risk Assessment of Cd. II. Human health

Predicted Cd-U scenario's show no risk for non smoking adults, except for individuals with depleted iron stores; smokers are at risk

Predicted scenario's	Cd-U (µg/g creatinine)
1a. Adults non-smokers	0.16-0.56
1b. Adult smokers	0.41-1.56
2a. Adults depl. iron stores, non-smokers	0.26-1.04
2b. Adults depl. iron stores, smokers	0.51-2.04

Note: NOAEL is 2/3= 0.66 µg Cd/g creatinine

Risk Assessment of Cd. II. Human health

Risk for non-smoking adults in the general population?

• The predicted Cd-U in iron-deficient individuals is above the NOAEL, iron-deficiency is common mainly in women at childbearing age. The predicted Cd-U values for these group were calculated with a 6 % absorption factor rather than 3%.

• A toxicokinetic model however concluded that the upper ranges of Cd-U are best described when selecting a 3% GI absorption rate for a kidney Cd half-life of 13.6 years (predicted/observed ratio 0.9-1.3; iron deficient individuals included).

• The rapporteur acknowledges that GI absorption rates up to 10% may exist during certain periods of iron deficiency, but that it is incorrect to apply the largest GI factor for lifetime exposure on also the largest dietary Cd intake values.

• The draft EC report has still used the 6% GI factor and concluded 'risk of Cd in the general population of EU excluding non-smoking, non iron-deficient adults'.

Risk Assessment of Cd. II. Human health

Regional assessment for the soil compartment in EU, conclusion for human health:

- Conclusions (ii) (no further risk reduction measures beyond those applied) for the non-smoking population, i.e. no risk predicted at current Cd emission for the ‘average population’.

- However, risk factors below 1.0 may not be protective enough for all sections of the general population because of the large variability in food Cd concentrations, dietary habits and nutritional status.

Conclusions

Risk is predicted but no countermeasures have yet been taken at an EU wide scale

The magnitude of risk critically depends on 2 factors

1. The interpretation of the low-level effects of Cd on kidneys: are they clinically relevant at population level?
2. The estimate of the (moderate) accumulation depends on the correct estimate of the leaching of Cd

At National (Belgian) scale: January 2006, a press release after a paper that came out:

'Environmental exposure to cadmium and risk of cancer:a prospective population-based study' *(Nawrot et al. , The Lancet)*

•prevalence of lung cancer was significantly associated with Cd-U in an area historically contaminated by Zn&Cd in Belgium

• claims (in the press) of 3000 persons potentially affected

•Interpretation: 'Historical pollution from non-ferrous smelters continues to present a serious health hazard,necessitating targeted preventive measures'

	Low exposure (n=473)		High exposure (n=521)	
	Women (n=257)	Men (n=216)	Women (n=266)	Men (n=255)*
Lung (ICD 162·0–163·9, 196·1)	1	2	6	10
Colon (ICD 153·0–154·1)	3	..	2	4
Gastric (ICD 151·9)	1	2	..	2
Gall bladder and pancreas (ICD 156·0, 156·2, 157·0, 157·8)	..	1	2	1
Urinary (ICD 188·0–189·0)	..	..	..	2
Prostate (ICD 185·0)	..	4	..	2
Uterus and ovaries (ICD 182·0, 183·0)	5	..	1	..
Breast (ICD 174·0)	..	..	4	..
Other (ICD 172·0, 200·0–209·9)	4	4	3	4

*Of 42 men with occupational exposure to cadmium, four developed lung cancer, one gallbladder cancer, one prostate cancer, one urinary bladder cancer, and one cancer of unspecified origin with generalised metastases.

Table 2: **Number of participants who developed cancer, by study area and sex**

(Nawrot et al., The Lancet)

	Total cohort (n=994)		Environmental exposure (n=952)*	
	Hazard ratio (95% CI)†	p	Hazard ratio (95% CI)†	p
All cancer‡				
Doubling of 24-h urinary cadmium excretion	1·31 (1·03–1·65)	0·026	1·29 (1·00–1·66)	0·050
Doubling of cadmium concentration in soil	1·10 (0·95–1·27)	0·189	1·08 (0·93–1·26)	0·298
High-exposure vs low-exposure area	1·31 (0·81–2·12)	0·276	1·28 (0·77–2·13)	0·333
Lung cancer§				
Doubling of 24-h urinary cadmium excretion	1·70 (1·13–2·57)	0·011	1·73 (1·09–2·72)	0·019
Doubling of cadmium concentration in soil	1·57 (1·11–2·24)	0·012	1·49 (1·04–2·14)	0·032
High exposure vs low-exposure	4·17 (1·21–14·4)	0·024	3·58 (1·00–12·7)	0·049

*Excludes 42 men with history of occupational exposure to cadmium, eight of whom developed cancer. †Adjusted for sex, age, and smoking. ‡n=70 in total cohort and n=62 in group with environmental exposure. §n=19 in total cohort and n=15 in group with environmental exposure.

Table 3: **Risk of cancer**

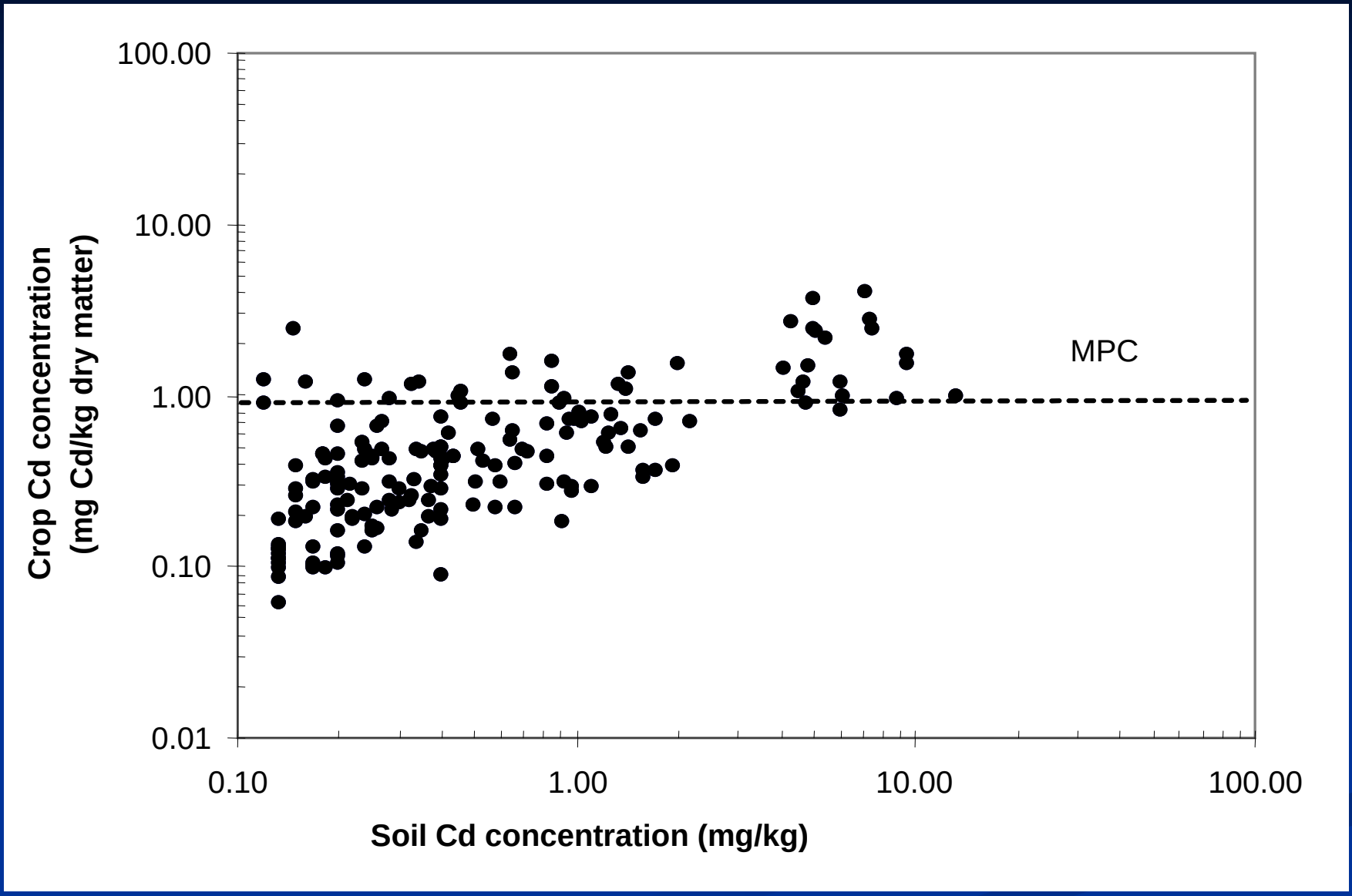
(Nawrot et al., The Lancet)

•Risk assessment of the local Cd contamination was accelerated as a result of the lung cancer study

• Soil properties are identified at which the crops do not exceed the MPC's

• Current air and houshold dust concentrations are not elevated; lung cancer effects likely reflect the historical exposure

Compilation of crop Cd concentrations in contaminated and non contaminated areas



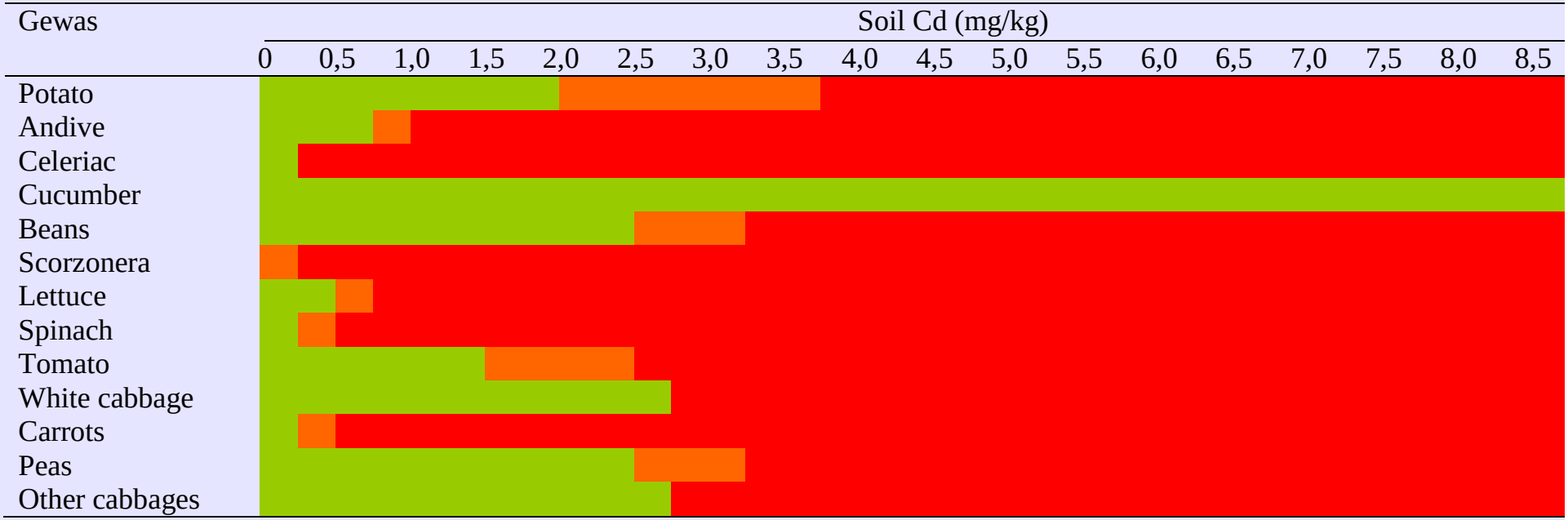
(Jansson, Römkens, Ruttens and Smolders, 2006, unpublished)

Predicted soil Cd (mg/kg) at which a fractions of samples exceeds the MPC

Soil pH	Average value=MPC	<10% samples above MPC	<5%samples above MPC
pH_{KCl} = 4,5	1,4	0,3	0,2
pH_{KCl} = 5,5	2,4	0,5	0,3
pH_{KCl} = 6,5	4,1	0,8	0,6

(Jansson, Römkens, Ruttens and Smolders, 2006, unpublished)

Look-up table for crops that can be grown in Belgium/The Netherlands without violating the MPC at soil pH_{KCl}=5,5. Green: <5% above MPC; orange<10% above MPC; red>10% above MPC



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